Modeling Studies of Direct (in Radiation) and Indirect (in Cloud Microphysics) Effects of Aerosols Using the NASA Unified WRF

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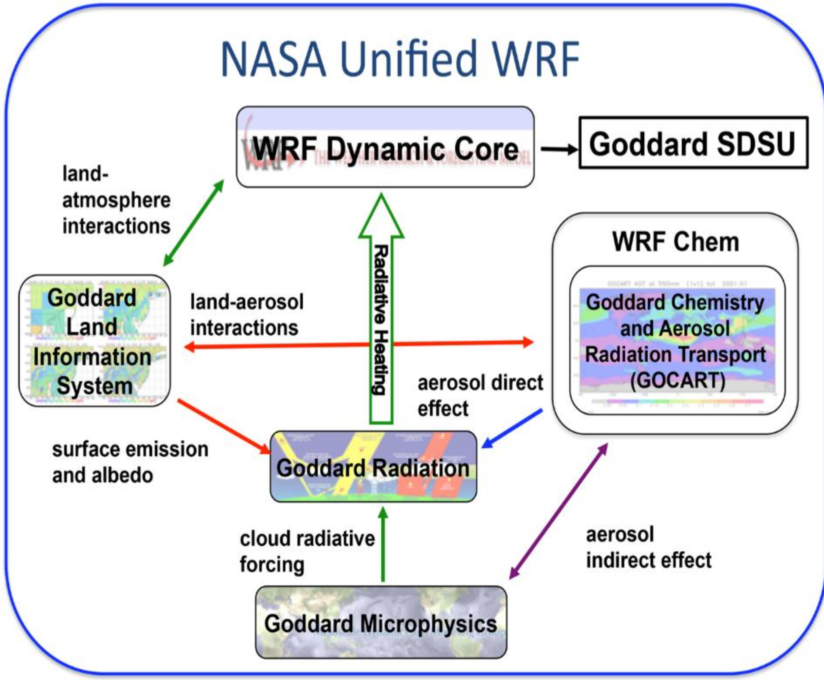

Fig. 1

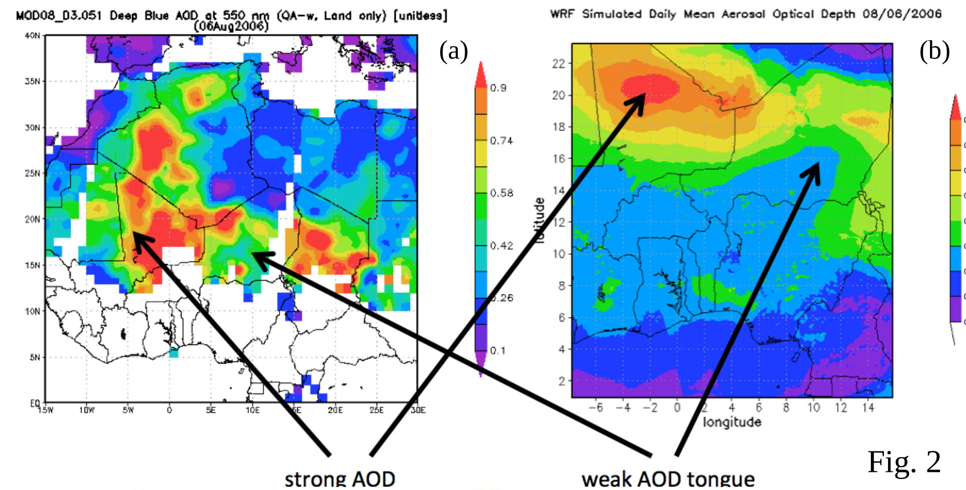

Fig. 2

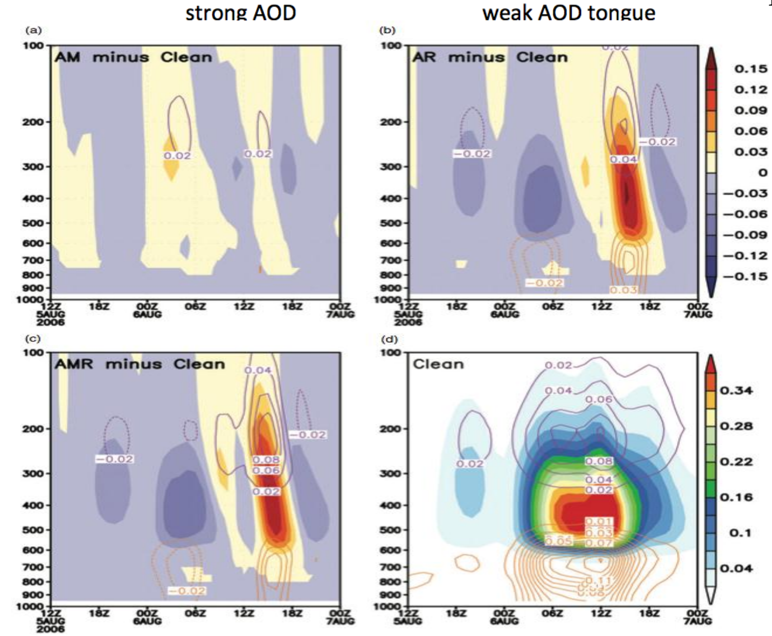

Fig. 3

To study both direct and indirect aerosol effects, an aerosol–microphysics–radiation coupling model was implemented. When the aerosol direct effect was activated in the model, the onset of convective precipitation was delayed about 2 h, in conjunction with the delay in the activation of cloud condensation and ice nuclei.

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Shi, J. J., T. Matsui, W.-K. Tao, C. Peters-Lidard, M. Chin, Q. Tan, K. Pickering, N. Guy, S. Lang, and E. Kemp., 2014: Implementation of an Aerosol-Cloud Microphysics-Radiation Coupling into the NASA Unified WRF: Simulation Results for the 6-7 August 2006 AMMA Special Observing Period. *Quart. J. Roy. Meteor. Soc.*, **140**, 2158-2175, DOI: 10.1002/qj.2286. http://onlinelibrary.wiley.com/doi/10.1002/qj.2286/abstract

Data Sources: In this study, an aerosol–microphysics–radiation coupling, using Goddard microphysics and radiation schemes, was successfully implemented into the NASA Unified WRF (NU-WRF) shown in Fig. 1. In order to study both the direct (in radiation) and indirect (in cloud microphysics) effects of aerosols, four different NU-WRF- GOCART (WRF-Chem) coupled simulations were conducted: i) aerosol effects included in the cloud microphysics but not radiation (Exp. AM); ii) full aerosol effects in radiation but minimal in the cloud microphysics with aerosol values set to the absolute minimum values in the atmosphere (Exp. AR); iii) full aerosol effects for both microphysics and radiation (Exp. AMR); and iv) no aerosol effects on radiation and minimal (i.e. a clean environment) on the microphysics (Exp. Clean), for an mesoscale convection system (MCS) that passed through the Niamey, Niger area on 6–7 August 2006 during an AMMA special observing period. Conducting a reasonable simulation of MCSs in this region has historically been difficult as the initial and boundary conditions from the global analyses (e.g. NCEP GFS or ERA-Interim) covering this area are not as reliable as those covering other parts of the world. In this study, NU-WRF was initialized from ERA-Interim global reanalysis data. Time-varying lateral boundary conditions, also from the same reanalysis data, were provided at 6 h intervals. The model was integrated for 48 h, from 0000 UTC 5 August to 0000 UTC 7 August 2006. For GOCART, the global GOCART simulation driven by the Goddard Earth Observing System Data Assimilation System (GEOS DAS with output saved every 3 h) was used for the initial and time-varying lateral boundary conditions.

Technical Description of Figures:

Figure 1: Systematic diagram to show Goddard physics packages included in the NASA Unified WRF.
Figure 2: (a) MODIS-Terra Deep Blue AOD agrees well with (b) WRF simulated aerosol optical depth (AOD) on 6 August 2006, but WRF simulated AOD has a much higher resolution at 6-km. Both show a weak AOD tongue in the central region of Niger and a strong AOD region in Mali.
Figure 3: Time series of the difference in area-mean cloud hydrometeors between (a) Exp. AM, (b) Exp. AR, (c) Exp. AMR and Exp. Clean. Orange contours are for cloud plus rain, purple contours ice, and shading snow plus graupel; solid and dashed lines indicate positive and negative respectively. (d) Time series of area-mean cloud hydrometeor profiles from Exp. Clean.

Scientific significance, societal relevance, and relationships to future missions: Aerosols affect the Earth's radiation balance directly and cloud microphysical processes indirectly via the activation of cloud condensation and ice nuclei. These two effects have often been considered separately and independently, hence the need to assess their combined impact given the different nature of their effects on convective clouds. To study both effects, an aerosol–microphysics–radiation coupling, including Goddard microphysics and radiation schemes, was implemented into the NASA Unified Weather Research and Forecasting model (NU-WRF). Fully coupled NU-WRF simulations were conducted for a mesoscale convective system (MCS) that passed through the Niamey, Niger area on 6–7 August 2006 during an AMMA special observing period. When the aerosol direct effect was activated, regardless of the indirect effect, the onset of MCS precipitation was delayed about 2 h, in conjunction with the delay in the activation of cloud condensation and ice nuclei. Overall, for this particular environment, model set-up and physics configuration, the effect of aerosol radiative heating due to mineral dust overwhelmed the effect of the aerosols on microphysics.

Earth's Climate Sensitivity: Apparent Inconsistencies in Recent Analyses

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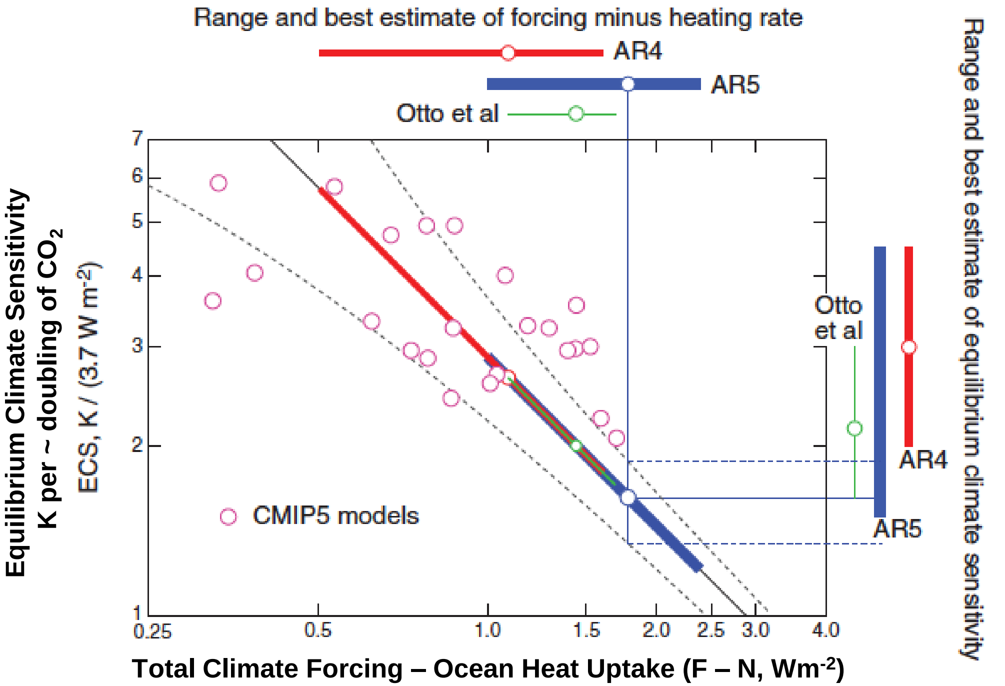

- **Recent assessments of climate sensitivity exhibit apparent inconsistencies**
- **Causes must be identified and addressed, to reduce uncertainties in climate prediction**
- **Possible contributors include: (1) Underestimated *aerosol cooling*, (2) Overestimated *total forcing*, (3) Overestimated *climate sensitivity*, (4) Underestimated *ocean heating*, and/or (5) *Energy balance model* limitations**

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Technical Description of Figure:

The simplest conceivable way to describe climate change is with a basic energy balance equation: $\boldsymbol{(F - N) \times ECS = \Delta T}$

Here *F* is the forcing (greenhouse gas warming – aerosol cooling, etc., in watts/sq. meter), *N* is the heat uptake, mainly by the oceans, ΔT is the change in global mean surface temperature (the warming), and *ECS* is the factor that determines how much warming you get for a sustained, doubled CO_2 f**orcing**. Higher *ECS* means a larger surface temperature change would be produced by a given change in forcing. So a lot rests on the magnitude of *ECS*. For about the past hundred years, ΔT has been measured, and the two most recent *IPCC* reports (AR4 and AR5) use essentially the same values. The figure shows the relationship between the ranges of probable values for the net forcing (*F-N*) and *ECS* given in the two reports overall (red and blue lines, respectively), for the *Otto et al*. (2013, in green) paper, and for the individual AR5 models (purple circles). The thin, black, solid, diagonal line represents agreement among forcing, response, and *ECS*, based on the energy balance equation; dashed black lines show an estimated *ECS* confidence interval. If you project from the horizontal and vertical red lines to the black line, you see consistency for the AR4 values. However, for the (blue) AR5 values, the forcing is larger, so just the low end of the reported *ECS* range appears barely consistent, and roughly the same for *Otto et al*. (2013; green lines).

Scientific significance, societal relevance, and relationships to future missions:

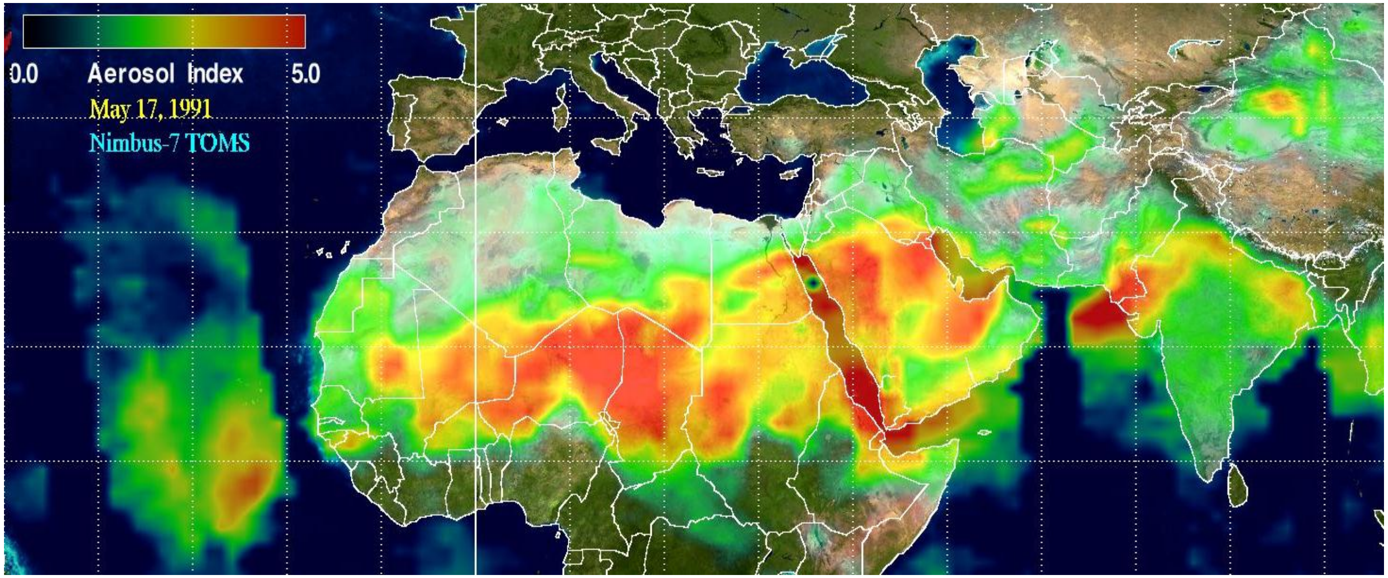
Equilibrium Climate Sensitivity (*ECS*) is a key diagnostic of global climate model predictive capability, relating in a simple way the "forcing" (*F*) of climate change due to changes in greenhouse gases, aerosols, and other factors, to the "response," which is usually taken as the global mean surface temperature change. Our paper uses a simple energy balance model to assess the consistency between the climate forcing postulated in the *Intergovernmental Panel on Climate Change* (*IPCC*) fifth assessment report (AR5; 2013), and the corresponding values of climate sensitivity given in the same report, in the previous *IPCC* report (AR4; 2007), and in a paper by *Otto et al*. (2013).

Energy balance considerations show a consistent relationship among forcing, response, and *ECS* for AR4. However, this is not the case for AR5 or the Otto et al. study. For AR5, aerosol negative forcing (a net cooling) is estimated as smaller than the value in AR4, and in addition, the positive forcing from greenhouse gases is slightly larger, due to the increasing atmospheric concentration of carbon dioxide. So for AR5 the net forcing increased, and the response (ΔT) is kept essentially the same as AR4. Yet the reported estimated range of the climate sensitivity in AR5 also remains almost the same as AR4. So for AR5, the three factors are not consistent with the simple energy balance model. Our paper raises these points, and asks (1) why in AR5 the aerosol forcing estimate is reduced, (2) given the increased net total forcing estimate, why *ECS* is not diminished relative to AR4, and (3) why the forcing-response-*ECS* relationship in AR5 is not consistent with simple energy balance considerations. We enumerate possible contributing factors: (1) underestimated aerosol cooling, (2) overestimated total forcing, (3) overestimated climate sensitivity, (4) underestimated ocean heating, and/or (5) energy balance model limitations. Improved measurements of aerosol direct and indirect forcing, and of ocean heat absorption, would help, along with further examination of climate model performance.

Improved Nimbus-7 TOMS view of the 1991 Gulf War Oil Fires Plume Shows Extensive Impact of Smoke Cloud

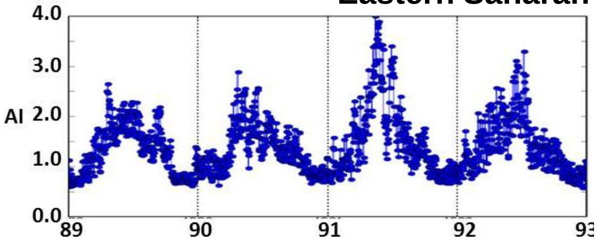
O.Torres, P.K. Bhartia, D. Larko, Code 614, NASA-GSFC, SSAI

Landsat TM-5, April 7, 1991

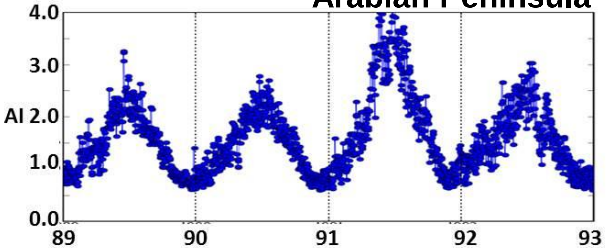


Nimbus7 TOMS Aerosol Index, May 17, 1991

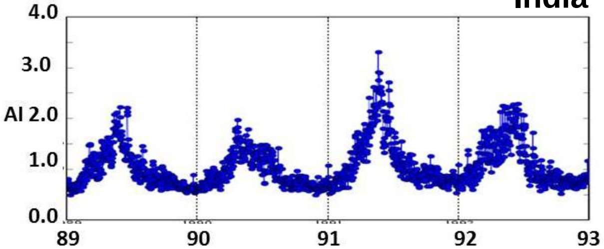
Eastern Saharan



Arabian Peninsula



India



The smoke plume formed in the aftermath of the Kuwait oil fields fires during the 1991 Persian Gulf War was observed by existing spaceborne instrumentation. Post-processed Nimbus-7 TOMS sensor data captured the spatial and temporal variability of the plume in terms of the Aerosol Index. The TOMS record shows that the smoke plume extended in both East and West directions from the source area, significantly more widespread than previously reported. The Aerosol Index increased by at least 50%, in relation to previous years, over a large area from the Eastern Saharan to India during the May-July 1991 period. This AI increase is equivalent to a similar percent increase in the atmospheric aerosol load.

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References:

Torres, O., P.K. Bhartia, D. Larko, and H. Jethva, 2014, Space view of the 1991 Gulf War Oil Fires Plume, AGU 2014 Fall Meeting, Special Session on Conflict Ecology, San Francisco, Ca.

Data Sources: NASA Total Ozone Mapping Spectrometer Aerosol Index data, NOAA National Centers for Environmental Predictions (NCEP) winds analysis, NASA Landsat Thematic Mapper.

Near 700 oil wells were set on fire in January and February 1991 by the retreating Iraqi army that had invaded Kuwait on August 2, 1990. It is estimated that five to six millions barrels of crude oil and 70 to 100 million cubic meters of natural gas per day were burned. The fires lasted for about eight months, the last one was extinguished by November 1991. Although the Nimbus7 Total Ozone Mapping Spectrometer (TOMS) had been in orbit since October 1978, the TOMS aerosol detection capability had not yet been developed. Therefore, the 1991 Gulf War oil fires plume was not seen by TOMS in real time. After the development of the TOMS Aerosol Index (AI) in 1995, however, the smoke plume associated with this historic event was retrospectively observed. Post-processed Nimbus-7 TOMS sensor data captured the spatial and temporal variability of the plume in terms of the Absorbing Aerosol Index.

Technical Description of Figures:

Graphic 1 (top left): High resolution Landsat TM-5 image on April 7, 1991 depicting the spread of individual oil well fires.

Graphic 2 (top right): Spatial extent of of the aerosol layer over a large region east and west of the source region as shown by the TOMS Aerosol Index. Combined analysis of TOMS observations and NCEP winds (700 mb) data indicate that the smoke plume mixed with desert dust layers forming a combined dust-smoke aerosol cloud that at times seemed to extend continuously westward from NW India to the Western Saharan. According to TOMS observations, the spatial extent of the Kuwait plume was significantly more widespread than previously reported.

Graphic 3: Monthly means (1989-1992) of regionally averaged TOMS Aerosol Index data over the Eastern Saharan (left), Arabian Peninsula (middle), and north-west India (right). The large increase in Aerosol Index (~50%) in 1991 is associated with a similar increase in atmospheric aerosol load.

Scientific significance and societal relevance: This work highlights the relationship between the atmospheric environment and armed conflict.